LBNL-60594

ERNEST ORLANDO LAWRENCE
BERKELEY NATIONAL LABORATORY

An Analysis of the DER Adoption Climate in Japan Using Optimization Results for Prototype Buildings with U.S. Comparisons

Nan Zhou, Chris Marnay, Ryan Firestone, Weijun Gao, and Masaru Nishida

Environmental Energy
Technologies Division

June 2006

http://eetd.lbl.gov/ea/EMS/EMS_pubs.html

To be published in the Energy and Buildings Journal

The work described in this report was funded by the Office of Electricity Delivery and Energy Reliability, Distributed Energy Program of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

Disclaimer

accepted for publication in Energy and Buildings

An Analysis of the DER Adoption Climate in Japan Using Optimization Results for Prototype Buildings with U.S. Comparisons

Nan Zhou,[1,*] Chris Marnay,[1] Ryan Firestone,[1] Weijun Gao,[2] and Masaru Nishida[3]

[1] Ernest Orlando Lawrence Berkeley National Laboratory, 1 Cyclotron Road, MS 90R4000, Berkeley, CA 94720-8136, USA

[2] Faculty of Environment Engineering, University of Kitakyushu, Hibikino 1-1, Wakamatsu-ku, Kitakyushu 808-0135, Japan

[3] Faculty of Engineering, Kyushu Sangyo University, Matsukadai 2-3-1, Higashi-ku, Fukuoka 813-8503, Japan

Abstract

This research demonstrates economically optimal distributed energy resource (DER) system choice using the DER choice and operations optimization program, the Distributed Energy Resources Customer Adoption Model (DER-CAM). DER-CAM finds the optimal combination of installed equipment given prevailing utility tariffs and fuel prices, site electrical and thermal loads (including absorption cooling), and a menu of available equipment. It provides a global optimization, albeit idealized, that shows how site useful energy loads can be served at minimum cost. Five prototype Japanese commercial buildings are examined and DER-CAM is applied to select the economically optimal DER system for each. Based on the optimization results, energy and emission reductions are evaluated. Significant decreases in fuel consumption, carbon emissions, and energy costs were seen in the DER-CAM results. Savings were most noticeable in the prototype sports facility, followed by the hospital, hotel, and office building. Results show that DER with combined heat and power equipment is a promising efficiency and carbon mitigation strategy, but that precise system design is necessary. Furthermore, a Japan-U.S. comparison study of policy, technology, and utility tariffs relevant to DER installation is presented.

Keywords: distributed energy resources, combined heat and power, building energy efficiency, commercial buildings, optimization, absorption cooling

1. Introduction

Energy consumption in Japan has been following a consistently rising trend, except for brief periods during the two oil crises. From 1990 to 2000 energy consumption by the residential/commercial sector increased 26.4%, reflecting changes in lifestyle and comfort [1]. Japan depends on energy imports that are becoming more costly, so encouraging on-site distributed energy systems in commercial buildings has become increasingly urgent [2]. Combined heat and power (CHP) and renewable generation are widely expected to spread, increasing energy efficiency and addressing global environmental problems [3]. Building heat loads are typically small relative to electricity loads, so capturing the benefit of building cooling using waste heat in absorption cycles is of particular importance; however, specifying such systems is especially challenging because of the endogenous relationship between displacing electricity requirements and meeting them with on-site generation.

The Japanese Ministry of Economy, Trade, and Industry (METI) is setting its new Long-Term Energy Supply and Demand Strategy to 2030. An interim report released in June 2004 proposes more decentralized energy systems (or microgrids). This new outlook includes a distributed generation development scenario wherein the share of self generation in total electricity supply exceeds 20% by 2030 [4].

Various efforts have been made to quantify the potential energy saving of CHP in buildings and to improve methods for evaluating overall efficiency [5,6,7]; however, while economics is key to the implementation of DER, an economic optimization design tool based on technology information and current tariffs and policy has yet to be developed for Japan. This research conducts an analysis of the potential for DER and CHP utilization in Japan. As part of this research, a information base of DER technologies, Japanese energy tariffs, and prototypical building energy loads has been developed, which can be used for future energy efficiency, climate change, and technology assessment research.

Using the Distributed Energy Resources Customer Adoption Model (DER-CAM), an analysis was conducted of economically optimal DER investments for different prototype buildings in the Tokyo climatic zone of Japan.

*Corresponding author:
Berkeley Lab, 1 Cyclotron Road MS 90R4000
Berkeley CA 94720-8136, USA
tel: 1(510) 486-5534 fax: 1(510) 486-6996
email: NZhou@lbl.gov

2. DER-CAM

Many DER and CHP assessment software programs are available in the U.S. and elsewhere, including Washington State University Energy Program's HEATMAP. It assesses the performance and economics of predetermined regional DER systems, and reports total system cost, system performance statistics, and environmental effects. The Computer Aided Simulation for Cogeneration Assessment Design Environment developed by the Air Conditioning and Sanitation Institute of Japan assesses efficiency, environmental effects, and economics of CHP for five prototype buildings: hotel, hospital, office building, sports facility, and factory.

Yamaguchi has conducted both energy saving and economic analyses for a DER system serving and placed between two office buildings [8,9]. Okuda has characterized the performance of the P15 07 micro gas turbine, and determined economically optimized operation strategies for it [10].

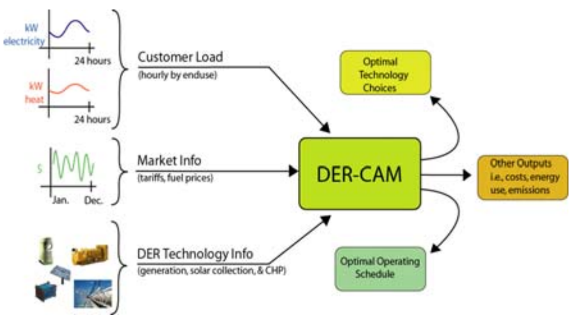

Fig. 1. DER-CAM Schematic

In all approaches, the analyst had to specify the DER system, i.e. the optimal equipment for different buildings cannot be found automatically. DER-CAM, developed by the Ernest Orlando Lawrence Berkeley National Laboratory (LBNL), is an optimization tool for DER technology selection. As shown schematically in Fig. 1., DER-CAM minimizes the annual energy cost of a given customer, including DER investment costs, based on input data covering DER technology cost and performance, electricity and natural gas tariffs, and hourly site end-use energy requirements, such as space heating, space cooling, domestic hot water, etc. DER-CAM reports the optimal technology selection and operating schedule.

Note that DER-CAM provides both the optimal equipment selection and an optimal operating schedule for provision of both electricity and heat loads. Together these show how the building's useful energy flow requirements can be met at minimum cost. Note also, that this is a simultaneous solution. Key trade-offs between equipment size, cost, and fuel purchases are all being respected, as well as the downsizing benefits to electrical systems that absorption cooling potentially offers [11].

3. Building, Market, and Technology Inputs

3.1 Utility Tariffs

Utility electricity and gas tariffs are key factors determining the economic benefit of a CHP installation. In Japan, there are three main components to each commercial building monthly electricity bill: 1. a fixed customer charge ($/month); 2. a demand charge proportional to maximum power consumption during the month ($/kW-month) (a typical monthly demand charge was 10-18 $/kW-month in 2004); and 3. a time-of-day and seasonally varying energy charge ($/kWh) (the energy price ranged from 0.08 to 0.18 $/kWh for on-peak power, and 0.04-0.05 $/kWh off-peak in 2004, which is close to the level of more expensive U.S. regions).

At the time of this analysis, natural gas prices in Japan were roughly two to three times higher than in the U.S. Even the favorable rate for CHP sites was still higher than typical U.S. rates. The rate for buildings with CHP has an around 0.0306 $/kWh energy charge, a 64 $/month customer charge, and a 0.00082 $/kWh maximum seasonal charge (a special surcharge on gas consumption from Dec.-Mar.). Additionally, an unusual flow rate charge is also levied monthly in Japan, based on annual maximum hourly consumption (a typical monthly charge is 8.30 $/m^3-h). A typical gas price for CHP in Japan is from 0.033 to 0.05 $/kWh.[1]

3.2 Building Sizes

The five prototype buildings considered are: office building, hospital, hotel, retail store, and sports facility. Fig. 2 shows the wide distributions of floor space for various building types in Japan [12]. Most office buildings are less than 5,000 m^2, but there are many above 10,000 m^2 as well as under 2,000 m^2. Because DER is most attractive for larger buildings, 10,000 m^2 was used as the representative floor area size for all buildings.

3.3 Energy Loads

Detailed knowledge of energy end-use loads is important for selecting an appropriate DER system. In Japan, when designing CHP systems, estimates of energy consumption intensities of various building types are typically obtained from the *Natural Gas Cogeneration Plan/Design Manual 2002*, and this source is used here [13]. This manual reports annual

[1] The exchange rate used was that of October, 2003: US$1 = JP¥ 120.

energy consumption and fractions of consumption by month and hour, so load shapes can be estimated. It is derived from actual buildings throughout Japan, but is not differentiated by climate.

Examples of hourly load shapes (cooling and space heating) for the office building are shown in Fig. 3 and Fig. 4. Significant seasonal variation can be seen in cooling and space heating load, attributable to Japan's seasonal character. The cooling electricity peaks average 150-200 kW during the summer and 50-70 kW during fall and spring, while the daytime space heating loads are approximately 500-600 kW with a dramatic winter peak load of 974 kW.[2] Although not shown in the figures, the electricity only loads vary between 300-400 kW throughout the year. The hot water loads peak in winter around noon at about 32 kW.

3.4 DER Technology Options

Table 1 shows the DER technologies used and their current properties in the U.S. It is itemized by natural gas engine (GE), gas turbine (GT), microturbine (MT), fuel cell (FC), and photovoltaics (PV). All equipment (besides PV) is natural gas fired and can be purchased for electricity generation only, and with heat recovery for heating (HX), or with heat recovery for heating and absorption cooling (ABSHX). Numbers at the end of each name in Table 1 refer to the rated electrical capacity of the equipment. Data includes capacity, lifetime (in years), turnkey capital costs, maintenance costs, heat rate, and electrical efficiency.

Similar data was also collected for some Japanese DER equipment. Fig. 5 compares DER turnkey costs of gas engines in Japan and the U.S. There is little difference in the range 3,000 kW to 5,000 kW. At higher capacities, Japanese prices are lower, while the more relevant here smaller units, are significantly more expensive. However, CHP subsidies of about 1/3 of turnkey costs are available throughout Japan making DER costs for units in the relevant size range for this study effectively similar to those in the less subsidized areas of the U.S.

3.5 DER Incentives

Table 2 shows the subsidies collected by selected U.S. sites, as found by Bailey et.al. [14]. The incentives for DER installation vary regionally, and include rebates and low-interest loans. Historically, under federal law and Federal Energy Regulatory Commission (FERC) regulations, individual states determine incentives for qualifying facilities (QFs), typically larger (>~1 MW). Small scale CHP is

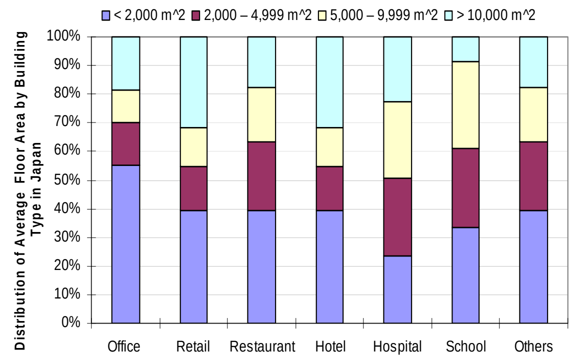

Fig. 2. Size Distributions of Building Floor Space

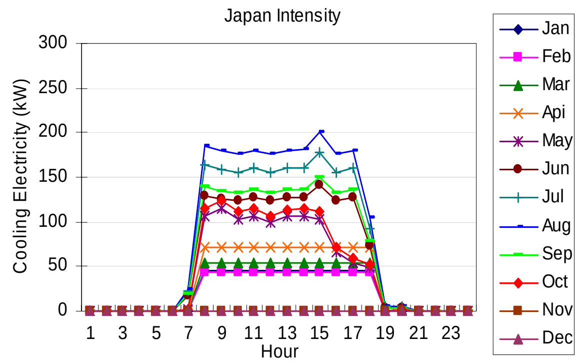

Fig. 3. Diurnal Cooling Electricity Load

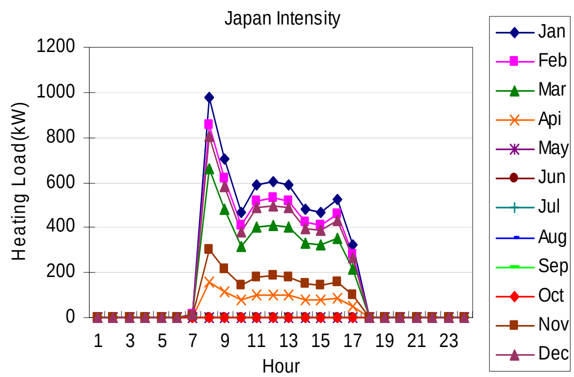

Fig. 4. Diurnal Heating Natural Gas Load

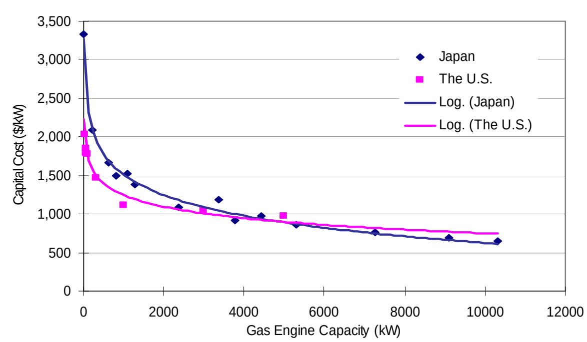

Fig. 5. Turnkey CHP Costs in Japan and the U.S.

---

[2] Both electricity and NG use are here reported in kW, where 1 kWh = 3.6 MJ or 3412 Btu.

entirely under state and local jurisdiction, and incentives may include rebates on DER project costs, energy tariff reductions, or utility purchase of excess electricity. Although determining incentives available to an individual site is difficult, example programs from California, New York, and elsewhere show many sites can and do receive substantial incentives.

The California Public Utilities Commission (CPUC) introduced a statewide Self-Generation Incentive Program (SGIP) in September 2000. It provides financial incentives to customers that install new qualifying self-generation equipment to provide all or a portion of their electricity needs. Funding of $125 million annually statewide is provided for self-generation of up to 1 MW. Qualifying facilities can receive incentives up to 50% of project costs.

The New York State Public Service Commission has implemented a system benefits charge applied to all electric rates to provide a fund for the purposes of increasing energy efficiency investments. From the fund, the New York State Energy Research and Development Authority offers funding of approximately $12 million annually for DER projects in industrial, commercial, municipal, and institutional organizations.

At the federal level, the U.S. Department of Defense's Climate Change Fuel Cell (DODCCFC) program was initiated in 1995 and provides rebates of up to $1,000/kW for fuel cell installations with a capacity of at least 3 kW. A total of 234 fuel cells have received grants and more than $30 million been awarded. In 2004, awards were made for 26 fuel cells totaling $6.0 million (FY2003 funds). In 2005, approximately $1.2 million were available for rebates.

Subsidies also exist in Japan. As shown in Table 3, CHP systems are eligible for a rebate of 1/3 to half of installation costs; and interest rates as low as 1.5% are available from both national and local governments. Most of the incentives are provided by the New Energy and Industrial Technology Development Organization (NEDO) and METI through various programs.

4. Results for Prototype Buildings

DER-CAM optimizations were executed using the U.S. technology data, assuming a 1/3 subsidy across the board to all the technologies considered. Technology costs in Japan are effectively similar to those in the U.S. based on discussion in *3.4* and *3.5*. The average efficiency of the Japanese macrogrid was assumed to be 36.6%. and CO2 emissions were assumed to be 0.66 kg/kWh, equivalent to elemental carbon emissions of 0.18 kg/kWh ; that is, all displaced macrogrid generation is assumed to be from fossil power plants.

In the results, whole system efficiency is the percentage of fuel energy used by the DER system applied to an end use as either electricity or heat. In the U.S., FERC has an alternative definition of efficiency defined as:

$$\text{FERC Efficiency} = \frac{[\text{Electrical Energy Produced}] + 1/2[\text{Recovered Heat Utilized}]}{[\text{HHU of Fuel Consumed}]} \times 100\%$$

For each building type modeled, three DER-CAM scenarios were considered:

- *Do-Nothing*: No DER investments are allowed. This scenario provides the baseline annual energy cost, consumption, and emissions prior to DER investment.
- *DER*: DER investment in electricity generation only, i.e. no CHP allowed.
- *DER with CHP*: DER investment in any of the electricity generation and heat recovery and utilization devices available.

CHP shifts the balance of utility purchases, reducing utility electricity purchases but significantly increasing natural gas requirements. Recovered heat from the equipment can be used to offset natural gas used for heating and/or electricity used for cooling. Examples of office and hospital buildings are shown below.

4.1 Office Building

Even for office buildings, which have low capacity factors, on-site generation may be economic because of high on-peak electricity prices and demand charges, combined with the discounted CHP natural gas rates. Table 4 shows example DER-CAM results for the office building. The Do-Nothing total energy bill is $317,400. In the DER without heat recovery scenario, a 300 kW natural gas engine is selected, resulting in decreased electricity purchases and increased natural gas purchases. Total annual energy costs (including capital and maintenance costs) are reduced by about 4.7% ($15,000). For the DER with CHP scenario, the 300 kW natural gas engine with heat recovery for heating and absorption cooling was chosen. Compared with the Do-Nothing case, the total annual energy bill savings are 12.3% ($40,000) with a payback period of 4.7 years. Fig. 6 and Fig. 7 show the January weekday natural gas loads and how they are met by the CHP system. The peak load is about 1200 kW at 8 am, 600 kW being met by recovered heat. Fig. 8 and 9 show the electricity loads on July day. The peak electricity load is 569 kW, 300 kW of which is met by DER. The peak cooling electricity load is reduced 177 kW by absorption cooling, and the net electricity purchase from the macrogrid is reduced to 198 kW.

Table 1 DER Technology Information for the U.S.

Technology	Name	Capacity kW	Lifetime years	Capital Cost $/kW	Fixed Annual Cost* $/kW	Variable Annual Cost* $/kW	Heat Rate kJ/kWh	HHV Efficiency %
Fuel Cell	FC--00200	200	10	5005	0	0.029	10000	36%
	GT--01000	1000	20	1403	0	0.0096	16438	22%
	GT--05000	5000	20	779	0	0.0059	13284	27%
	GT--10000	10000	20	716	0	0.0055	12414	29%
	GT--25000	25000	20	659	0	0.0049	10496	34%
Gas Turbine	GT--40000	40000	20	592	0	0.0042	9730	37%
	MT--00028	28	10	2263	0	0.015	15929	23%
	MT--00060	60	10	1828	0	0.015	14400	25%
	MT--00067	67	10	1708	0	0.015	14286	25%
	MT--00076	76	10	1713	0	0.015	14876	24%
Microturbine	MT--00100	100	10	1576	0	0.015	13846	26%
Natual Gas Reciprocating Engine	NG--00030	30	20	1044	0	0.02	13080	28%
	NG--00060	60	20	991	0	0.018	12528	29%
	NG--00075	75	20	974	0	0.017	12360	29%
	NG--00100	100	20	1030	0	0.018	12000	30%
	NG--00300	300	20	790	0	0.013	11613	31%
	NG--01000	1000	20	720	0	0.009	10588	34%
	NG--03000	3000	20	710	0	0.009	10286	35%
	NG--05000	5000	20	695	0	0.008	9730	37%
Photovoltaic	PV--00010	10	30	8740	12	0	0	100%
	PV--00025	25	30	8140	12	0	0	100%
	PV--00050	50	30	7940	12	0	0	100%
	PV--00100	100	30	7840	12	0	0	100%
Fuel Cell with Heat Recovery for Heating	FC--HX--00200	200	10	5200	0	0.029	10000	36%
Gas Turbine with Heat Recovery for Heating	GT--HX--01000	1000	20	1910	0	0.0096	16438	22%
	GT--HX--05000	5000	20	1024	0	0.0059	13284	27%
	GT--HX--10000	10000	20	928	0	0.0055	12414	29%
	GT--HX--25000	25000	20	800	0	0.0049	10496	34%
	GT--HX--40000	40000	20	702	0	0.0042	9730	37%
Microturbine with Heat Recovery for Heating	MT--HX--00028	28	10	2636	0	0.015	15929	23%
	MT--HX--00060	60	10	2082	0	0.015	14400	25%
	MT--HX--00067	67	10	1926	0	0.015	14286	25%
	MT--HX--00076	76	10	1932	0	0.015	14876	24%
	MT--HX--00100	100	10	1769	0	0.015	13846	26%
Gas Engine Heat Recovery for Heating	NG--HX--00030	30	20	1442	0	0.02	13080	28%
	NG--HX--00060	60	20	1362	0	0.018	12528	29%
	NG--HX--00075	75	20	1336	0	0.017	12360	29%
	NG--HX--00100	100	20	1350	0	0.018	12000	30%
	NG--HX--00300	300	20	1160	0	0.013	11613	31%
	NG--HX--01000	1000	20	945	0	0.009	10588	34%
	NG--HX--03000	3000	20	935	0	0.009	10286	35%
	NG--HX--05000	5000	20	890	0	0.008	9730	37%
Fuel Cell with Heating and Cooling	FC--ABSHX--00200	200	10	5366	9.69	0.029	10000	36%
Gas Turbine with Heating and Cooling	GT--ABSHX--01000	1000	20	2137	10.37	0.0096	16438	22%
	GT--ABSHX--05000	5000	20	1149	4.03	0.0059	13284	27%
	GT--ABSHX--10000	10000	20	1025	2.76	0.0055	12414	29%
	GT--ABSHX--25000	25000	20	859	2.12	0.0049	10496	34%
	GT--ABSHX--40000	40000	20	746	1.88	0.0042	9730	37%
Microturbine with Heating and Cooling	MT--ABSHX--00028	28	10	3046	23.49	0.015	15929	23%
	MT--ABSHX--00060	60	10	2420	19.5	0.015	14400	25%
	MT--ABSHX--00067	67	10	2201	15.87	0.015	14286	25%
	MT--ABSHX--00076	76	10	2225	16.92	0.015	14876	24%
	MT--ABSHX--00100	100	10	2015	14.27	0.015	13846	26%
Gas Engine with Heating and Cooling	NG--ABSHX--00030	30	20	2029	22.56	0.02	13080	28%
	NG--ABSHX--00060	60	20	1851	18.93	0.018	12528	29%
	NG--ABSHX--00075	75	20	1796	17.84	0.017	12360	29%
	NG--ABSHX--00100	100	20	1774	16.51	0.018	12000	30%
	NG--ABSHX--00300	300	20	1465	12.08	0.013	11613	31%
	NG--ABSHX--01000	1000	20	1117	6.97	0.009	10588	34%
	NG--ABSHX--03000	3000	20	1038	4.37	0.009	10286	35%
	NG--ABSHX--05000	5000	20	967	3.45	0.008	9730	37%

Note* : cost for maintenance and operating

Table 2 Example Subsidies for DG at Selected U.S. Sites

Site	Installed Technology	Project Cost	Grants Received	Subsidy
A&P Supermarket	60 kW Capstone microturbine, CHP for space heating & desiccant dehumidification	$145,000	$95,000	66%
Guarantee Savings Building	3 x 200 kW Phosphoric Acid Fuel Cells, CHP, 350 kW (100 ton) adsorption chiller	$4,353,375	CPUC benefits through PG&E SGIP $1.5M, DODCCFC grant $600,000, and $2.6M loan from United Technologies Corp	48%
AA Dairy	digester biogas system converted 130kW diesel engine	$363,000	Environmental Protection Agency Ag. Star $24,000, local Soil Conservation District $120,000	40%
East Bay Municipal Utility District	10 x 60 kW Capstone microturbines, 630 kW (200 ton) absorption chiller and CHP	$3,900,000 (total funding), $184,522 for absorption chiller and heat exchanger	$855,000 rebate, and $1.9 million low interest loan	22%

4.2 Hospital

Table 5 shows results for the hospital building: the Do-Nothing total energy bill is $332,920. No equipment was selected for DER without heat recovery so there are no changes. For DER with CHP, a 300 kW natural gas engine with heat recovery for heating and absorption cooling was chosen. Compared with the Do-Nothing case, the total annual energy savings are 21.1% ($70,310) with a payback period of 3.4 years. Annual fuel cost are reduced by 40%. Fig. 10 and Fig. 11 show the natural gas loads for January and how the load is met from CHP. The peak load is 1252 kW, of which 438 kW is met by the CHP system. Fig. 12 and Fig. 13 show the electricity loads in July and how the CHP system meets these loads. The electricity load peaks at 10 A.M. at 461 kW, of which 300 kW is met by DER. Also, 44 kW of the peak cooling electricity load (161 kW) is offset by absorption cooling, reducing the net macrogrid electricity purchase to only 128 kW.

4.3 Comparative Results for all Buildings

Table 6 shows the installed capacity and natural gas used for the optimal CHP solutions for all prototype buildings. For office, hospital and hotel buildings, 300 kW gas engines with both heating and cooling equipment were selected. Cooling was provided by utilizing recovered heat in an absorption chiller. A larger size (1000 kW) gas engine with both heating and cooling equipment was selected for the Retail building. This may be attributable to its higher peak load. With more self generation and cooling offset by heat recovery, the high demand charge can be avoided. For the sports facility, because the cooling requirement is low, two 300 kW gas engines with only heat recovery were selected. The capacity factor is high in the hotel and hospital buildings, which are generally considered to be favorable CHP sites. The capacity factor is lowest in the retail building, in part because the selection of larger equipment to avoid the high on-peak electricity price and demand charge.

The natural gas purchased in the optimal case for all buildings shown in the table illustrates that the natural gas are most used for DER, except for sports facility where a lot of the heating requirement in the winter is directly met by natural gas due to the subsidized gas tariff for CHP installation. The effect of incentive tariffs on decision-making could be a topic for future work.

Fig. 14 shows the peak load shift effect of CHP in the prototype buildings in both winter and summer. In the winter, the heating peak load of the sports facility is most significant, followed by the hospital and office buildings. The biggest peak load reduction is seen in the sports facility (900 kWh), followed by the office building (550 kWh).

In the summer, the retail building shows the biggest utility electricity usage reduction; all peak loads can be economically met by self-generated power and waste heat recovery from CHP. The effect on air conditioning loads of heat recovery is seen in all of the buildings except the sports facility, for which heat recovery for cooling is not economic.

CHP also shifts the amounts and sources of carbon emissions. Fig.15 shows the carbon emissions reductions. CHP installation reduces these emissions for all prototype buildings. This reduction is most significant for the hotel (34% reduction) and retail building (34% reduction), followed by the hospital (32% reduction). Furthermore, CHP shifts the amounts and sources of annual energy costs. Fig.16 shows the economics of the CHP installations. For the sports facility, costs are reduced by 32%, followed by the hotel (23%) and the hospital (21%). The hotel has the shortest payback period (3.0 years), followed by the sports facility (3.3 years) and the hospital (3.4 years).

Table 7 states the system efficiency for the three scenarios (Do-Nothing, DER without CHP, and DER with CHP). The assumed macrogrid efficiency is used to calculate purchased electricity efficiency, Natural Gas combustion efficiency is used to calculate the gas direct use efficiency. The reported efficiency represents an overall efficiency of electricity generation and gas combustion of the DER system. This efficiency will be used if there is no electricity purchase from the grid. DER with CHP Whole System efficiency is the efficiency including both DER efficiency and the purchased electricity efficiency.

The entire system efficiency has been improved in all prototype buildings. The efficiency improvement is most significant for retail buildings (28.2 percentage point improvement), followed by the hotel (26.7) and the hospital (22.7). In all cases, the efficiency for DER without CHP is even lower than macrogrid efficiency demonstrating the importance of CHP for making DER competitive and effective for carbon mitigation.

CHP installation benefits all the prototype buildings considered, but hospitals, hotels, and sports facilities appear to have the most potential benefit. Although not as great as for the other building types, even office buildings, which are traditionally not considered DER candidates, can also reap benefit.

Table 3 Example Incentives for CHP in Japan

Program Name	Eligibility	Level
Development Bank of Japan: Energy Conservation Promotion	equipment over 50 kW, efficiency greater than 60%, CHP (any type of fuel)	interest rate 1.65%, and subsidy of 50% of investment
NEDO : Rational Energy Utilization Enterprise Support Project	office building ESCO projects using natural gas with an CHP installation project, and must be conducted by private enterprise	no more than 1/3 of cost, up to ¥500 M
METI: New Energy Enterprise Support Project	high efficiency natural gas CHP systems with natural gas CHP utilization energy supply equipment	no more than 1/3 of cost, bond covered up to 90%
NEDO: Local New Energy Installation Promotion Enterprise	local gov, projects executed by a local public agency and using a high efficiency natural gas CHP system	no more than 1/2 of cost

Table 4 Office Building DER-CAM Results

Case	Installed Capacity	Installed Technology	Installation Cost	Electricity Purchased	Natural Gas (k$)		Energy Cost	Total Cost	Energy Cost Reduction	Overall Cost Reduction	Pay Back Years
	kW		k$	k$	For DER	Gas only	k$	k$	%	%	a
Do-Noth.	0	0	0	275.3	0	42.1	317.4	317.4			
DER	300	NG--0030 0	36.4	125.2	112	28.8	266	302.5	-16.2%	-4.7%	6.1
DER with CHP	300	NG-ABSH X-00300	58.5	83.8	129.4	6.7	219.9	278.4	-30.7	-12.3%	4.7

Table 5 Hospital Building DER-CAM Results

Case	Installed Capacity	Installed Technology	Installation Cost	Electricity Purchased	Natural Gas (k$)		Energy Cost	Total Cost	Energy Cost Reduction	Overall Cost Reduction	Pay Back Year
	kW		k$	k$	For DER	Gas only	k$	k$	%	%	a
Do-Noth.	0	0	0	229.9	0	103.1	332.9	332.9			
DER	0	0	0	229.9	0	103.1	332.9	332.9			
DER with CHP	300	NG-ARSH X--00300	62.9	18.6	163	18	199.7	262.6	-40.01%	-21.1%	3.4

Table 6 Installed Capacity and Natural Gas Used for the Optimal CHP Solutions

	Office	Hospital	Hotel	Retail	Sports facility
installed technology	NG-ABSHX --00300	NG-ABSHX --00300	NG-ABSHX --00300	NG-ABSHX --01000	2 unit of NG--HX--00300
installed capacity (kW)	300	300	300	1000	600
capacity factor	49%	62%	72%	27%	56%
NG purchased for CHP (k$)	129.4	163	189.1	212.3	294.3
NG purchased for other use (k$)	6.7	18	9.5	3.4	277.1

Table 7 Prototype building system efficiency improvement

	Office	Hospital	Hotel	Retail	Sports facility
Macrogrid Electrical Efficiency	36.6%				
Natural Gas Combustion Efficiency	80%				
Do-Nothing System Efficiency	42.1%	49.5%	48.3%	41.2%	64.1%
DER without CHP Efficiency	31.0%	n/a	27.5%	34.0%	27.5%
DER with CHP System Efficiency	75.0%	74.1%	78.0%	69.4%	73.6%
DER with CHP System Efficiency (FERC)	53.0%	52.5%	54.5%	51.7%	52.3%
DER with CHP Whole System (DER & Util.) Efficiency	63.1%	72.2%	75%	69.4%	76.6%
Efficiency improvement (percentage points)	21.0	22.7	26.7	28.2	14.5

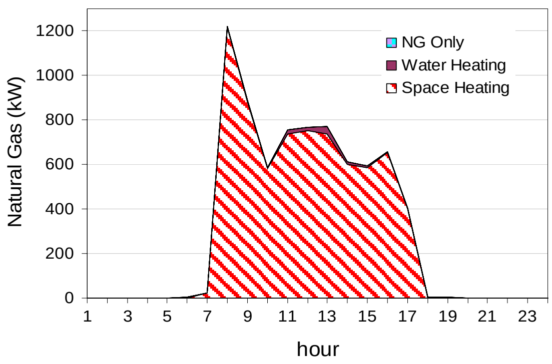

Fig. 6. Office Building Jan Natural Gas Use

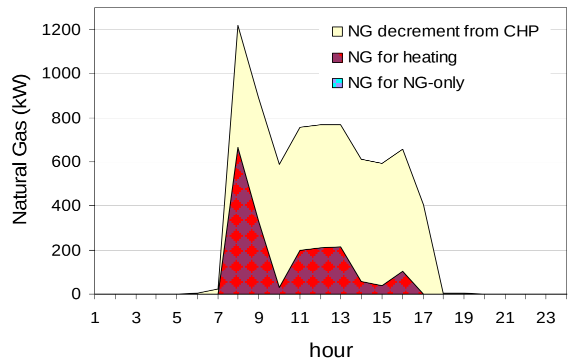

Fig. 7.Office Building Jan Natural Gas Load Provision with CHP

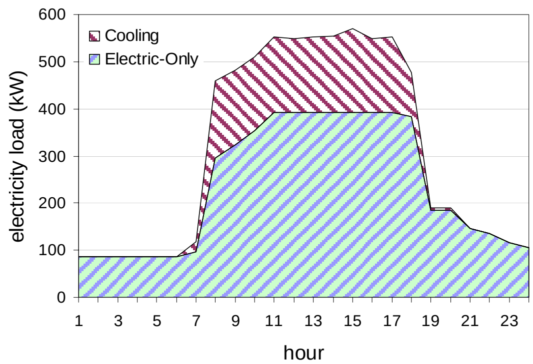

Fig. 8. Office Building Jul Electricity Use

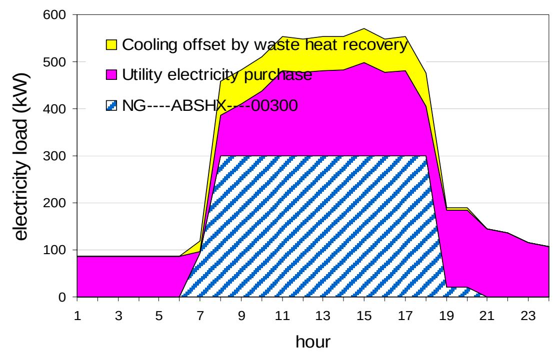

Fig. 9. Office Building Jul Electricity Load Provision with CHP

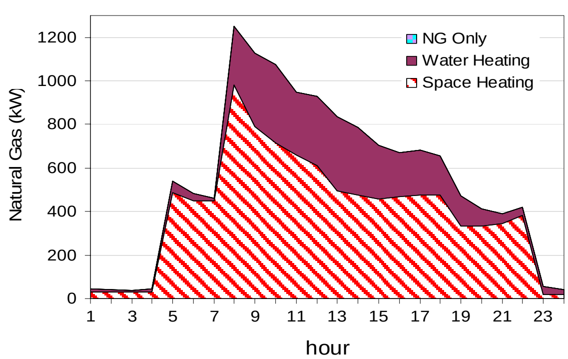

Fig. 10. Hospital Jan Natural Gas Use

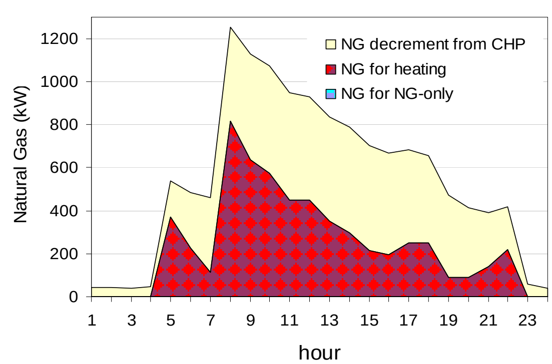

Fig. 11. Hospital Jan Natural Gas Load Provision with CHP

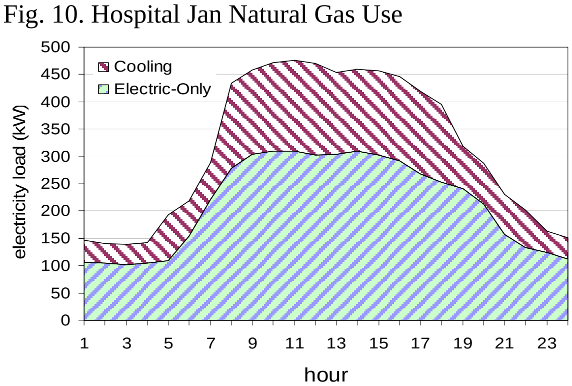

Fig.12. Hospital Jul Electricity Use

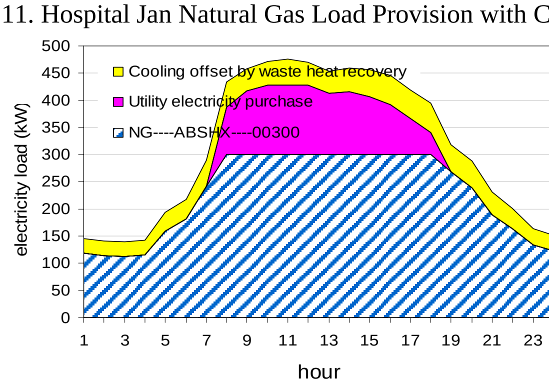

Fig. 13. Hospital July Electricity Load Provision with CHP

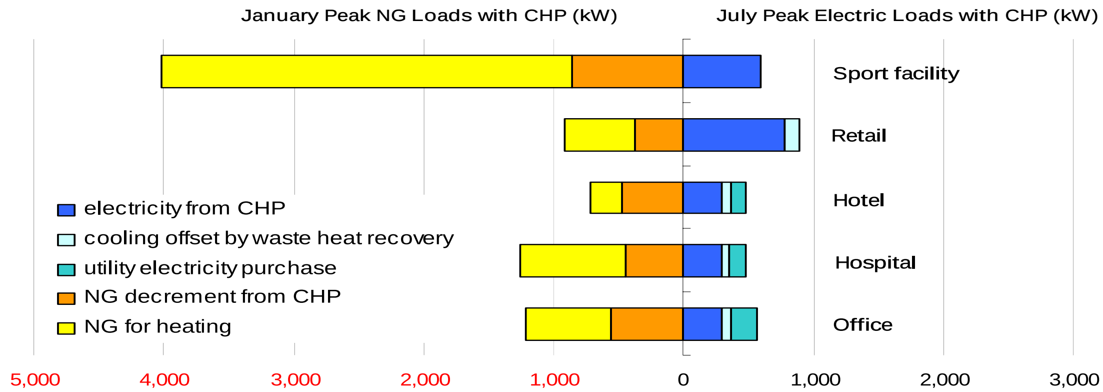

Fig. 14. Peak Load Shifts

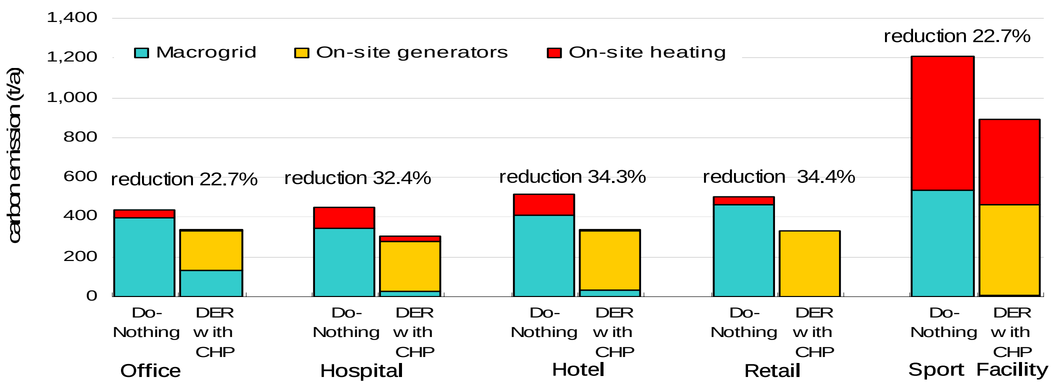

Fig. 15. Carbon Emission Reductions

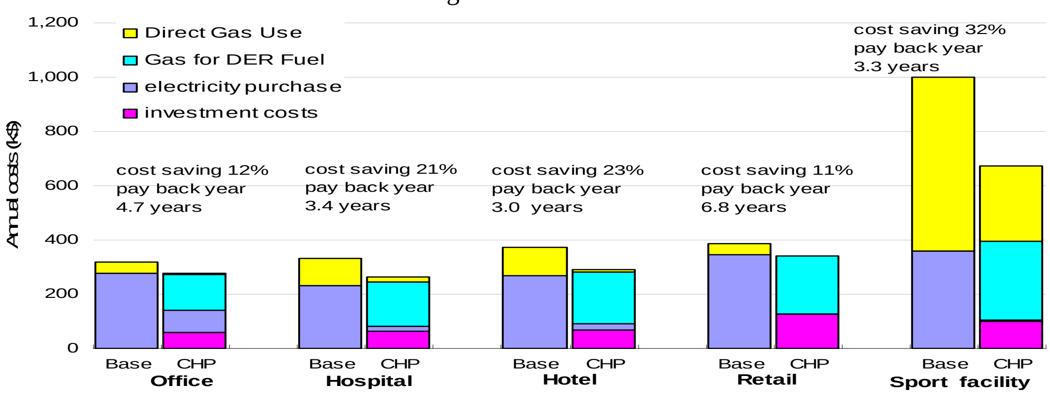

Fig. 16. Energy Bill Savings

Conclusions

This study examined five prototype commercial buildings in the Tokyo climate zone of Japan. DER-CAM was used to select the economically optimal DER system for each. Decreases in fuel consumption, carbon emissions, and energy costs were seen in the economically optimal results. Benefits were most noticeable for the sports facility, followed the hospital and the hotel. Further, this research suggests that even office buildings can possibly benefit from CHP. In contrast to popular opinion, the low capacity factors of office building installations can be compensated for because cooling can be such an economically valuable use for waste heat, displacing costly on-peak electricity, lowering demand charges, and downsizing necessary on-site generating capacity. Reciprocating engines are generators of choice in each case, and they are clearly the strongly incumbent technology. Absorption cooling is chosen in all buildings except the sports facility, underscoring its economic importance. While much more detailed analysis would be necessary to determine the viability of DER for any specific building, the potential payoff seems promising. Also, careful equipment selection and design will be required to achieve reasonable system performance. The results here provide a useful starting point for such an analysis of individual sites. Additionally, DER-CAM can be used for wider assessments of potential DER market penetration and the consequent possible efficiency and environmental benefits.

Acknowledgements

The authors thank the Japan Kyushu Industrial Technology Center for its support of this work. Also, prior development of DER-CAM has been supported by the U.S. Department of Energy, Distributed Energy Program, and by the California Energy Commission. The authors also thank Kazunari Shiraki (Osaka Gas Co.) and Atsushi Sakakura (Tokyo Gas Co.) for providing useful data, and Jennifer L. Edwards, Owen Bailey, and Peter Chan for their advice and editing that helped shape many of the concepts presented here. Prior development of DER-CAM has completed by Afzal S. Siddiqui, Michael Stadler, Kristina Hamachi LaCommare, and many others.

References

[1] ANRE. The Energy and Resources Today, Agency for Natural Resources and Energy, Japan, 2004. Available at http://www.enecho.meti.go.jp/english/energy/index.html

[2] H. Asano, K.I. Nishio, T. Imanaka, and E.I. Imamura. Modeling of Customer Adoption of Distributed Generation in Japan. 7th IAEE European Energy Conference, Bergen, Norway, Aug 2005.

[3] K. Nishio, and H. Asano. Supply Amount and Marginal Price of Renewable Electricity Under the Renewables Portfolio Standard in Japan, forthcoming in Energy Policy.

[4] METI, Japan.2004. Trend of energy consumption in residential and commercial sector, The Ministry of Economy, Trade and Industry (METI), http://www.enecho.meti.go.jp/english/energy/index.html

[5] Resource Dynamics Corporation. Integrated Energy Systems (IES) for Buildings: A Market Assessment, Vienna VA, U.S.A., Aug 2002. Available at http://www.bchp.org/pdfs/IES_Resource_Dynamics-FinalReport-0209.pdf

[6] K.H. LaCommare, R. Firestone, K. Maribu, N. Zhou, and C. Marnay. A Model of U.S. Commercial Distributed Generation Adoption, LBNL-57962, Jan 2006. (This and all LBNL reports listed are available at: http://eetd.lbl.gov/ea/emp/.)

[7] H. Li, L. Fu, K. Geng, and Y. Jiang. Energy Utilization Evaluation of CCHP Systems, Energy and Buildings 37 (2005) 493-501.

[8] Yamaguchi, Yohei, et al. 2003. Development of District Energy System Simulation Model Based On Detailed Energy Demand Model, Proceeding of Eighth International IBPSA Conference, Eindhoven,Netherlands, pp.1443-1450

[9] Yamaguchi, Yohei, et al.2003. Simulation of heat supply network connecting distributed cogeneration system and buildings, Proceeding of The 22th Annual Meeting Proceeding of The Japan Society of Energy and Resources, pp123-128

[10] Okuda, Hidenobu, et al. 2002. Evaluation of Cogeneration System Based on Performance Test Results of a Micro Gas Turbine, The Japan Society of Mechanical Engineers, No.02-7, The 8th National Symposium on Power and Energy Systems, pp.43-46.

[11] A.S. Siddiqui, C. Marnay, O. Bailey, K.H. LaCommare. Optimal Selection of On-Site Generation with Combined Heat and Power Applications, LBNL-56774, Nov 2004.

[12] The Ministry of Construction (present Ministry of Land, Infrastructure and Transport), Japan, Construction Data and Statistics Annual Report, 2000.

[13] Kashiwagi,Takao, Natural Gas Cogeneration Plan/ Design Manual 2002, Japan Industrial Publishing Co.,LTD, 2002.

[14] O. Bailey, C. Creighton, R. Firestone, C. Marnay, and M. Stadler, Distributed Energy Resources in Practice: A Case Study Analysis and Validation of LBNL's Customer Adoption Model, LBNL-52753, Feb 2003.